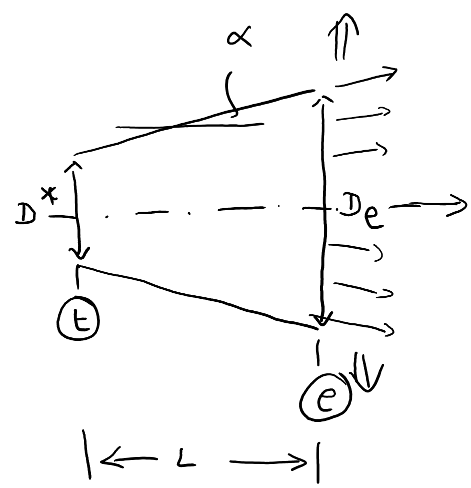
Nozzles, sec 11.3, read pp 520-540.

Diverging section nozzle shapes

Conical, perfect, maximum-thrust (aka minimum length), plug

Conical Nozzle, see fig 11.4



Exit flow is not axial. Some thrust is generated in the transverse direction.

$$\frac{D_e}{2} = \frac{D^*}{2} + L\tan\alpha$$

$$\Rightarrow D_e = D^* + 2L\tan\alpha$$

$$\frac{D_e}{D^*} = \left(1 + \frac{2L\tan\alpha}{D^*}\right)$$

$$\frac{A_e}{A^*} = \left(\frac{D_e}{D^*}\right)^2 = \left(1 + \frac{2L\tan\alpha}{D^*}\right)^2 \Rightarrow L = \frac{D^*}{2\tan\alpha}\left[\sqrt{\frac{A_e}{A^*}} - 1\right]$$

(see p 523)

Divergence loss for the conical nozzle (λ)

$$\lambda = \frac{1+\cos\alpha}{2} \qquad (11.14)$$

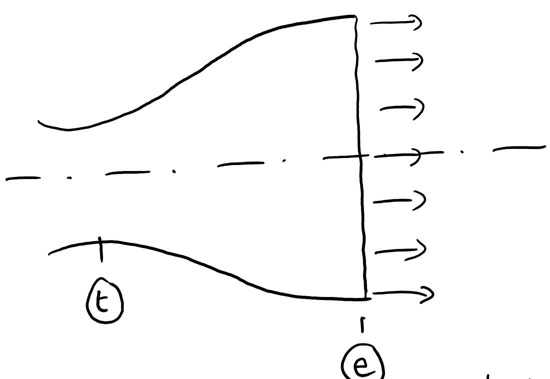
Advantage: simple

Disadvantage: Exit flow is not completely axial. This introduces divergence losses (λ)

Comment: λ can be reduced by decreasing the nozzle half angle (α). This, however, results in a longer nozzle for a given area ratio (A_e/A^*).

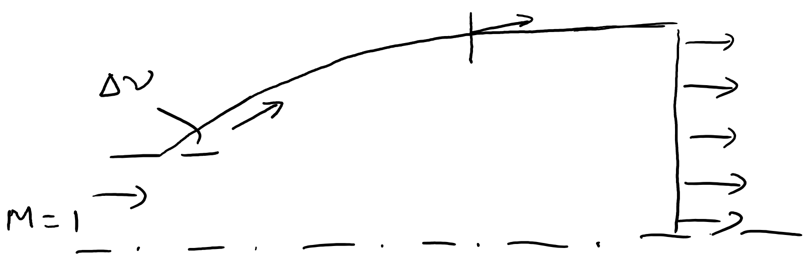
Perfect nozzle

Designed to achieve uniform, axial flow at exit.



Advantage: No divergence loss

Disadvantage: very long. The length needed to turn the flow the last few degrees is high.



See Fig (11.10)

Maximum thrust (or) minimum length nozzle

This nozzle is designed to generate the maximum thrust for a specified length. See Fig 11.13 and Fig 11.14 (observe that the exit flow is not axial)

Effect of back pressure

underexpanded jet : $p_e > p_a$

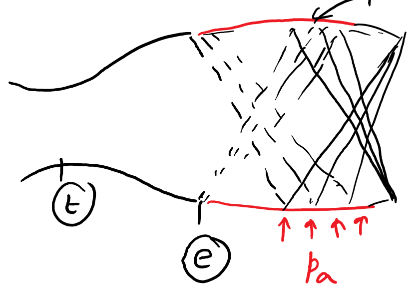


Fig 11.17 (a)

overexpanded jet : $p_e < p_a$

moderatly overexpanded

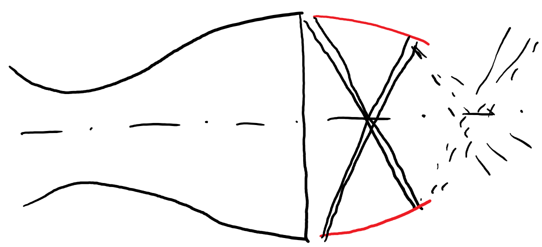


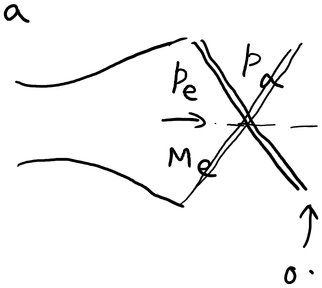
Fig (11.17 b)

Severely overexpanded jet may result in shock moving into the nozzle.

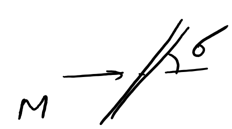
[Ex: consider case 4 of Pbm 11.2

$M_e = 4.25$, $p_e = 0.020476$ MPa, $p_a = 0.1$ MPa

$p_e < p_a$



$$\frac{p_a}{p_e} = 4.88$$



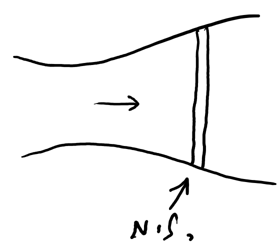
$$\frac{p_y}{p_x} = \frac{2\gamma}{\gamma+1} M_x^2 - \frac{\gamma-1}{\gamma+1} \quad (N.S.)$$

$$\frac{p_y}{p_x} = \frac{2\gamma}{\gamma+1} M_{xn}^2 - \frac{\gamma-1}{\gamma+1} \quad (\text{O.S.})$$

$$\frac{p_a}{p_e} = \frac{2\gamma}{\gamma+1} M_{en}^2 - \frac{\gamma-1}{\gamma+1} \Rightarrow M_{en} = 2.135$$

$$\underset{2.135}{M_{en}} = \underset{4.25}{M_e} \sin\sigma \Rightarrow 52.6^\circ$$

Fig 11.18 shows a severely overexpanded case where the shock has moved into the nozzle.



The actual scenario is the occurrence of O.S.

Fig 11.18 →